Draft version May 25, 2010
Preprint typeset using LaTeX style emulateapj v. 11/10/09

ANOMALOUS PARITY ASYMMETRY OF THE WMAP POWER SPECTRUM DATA AT LOW MULTIPOLES

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Draft version May 25, 2010

ABSTRACT

We have investigated non-Gaussianity of our early Universe by comparing the parity asymmetry of the WMAP power spectrum with simulations. We find that odd-parity preference of the WMAP data ($2 \leq l \leq 18$) is anomalous at 4-in-1000 level. We find it likely that low quadrupole power is part of this parity asymmetry rather than an isolated anomaly. Futher investigation is required to find out whether the origin of this anomaly is cosmological or systematic effect. The data from Planck surveyor, which has systematics distinct from the WMAP, will help us to resolve the origin of the anomalous odd-parity preference.

Subject headings: cosmic microwave background radiation — methods: data analysis

1. INTRODUCTION

For the past years, there have been great successes in measurement of Cosmic Microwave Background (CMB) anisotropy by ground and satellite observations (Hinshaw and et al. 2009; Nolta and et al. 2008; Dunkley and et al. 2009; Runyan and et al. 2003; Reichardt and et al. 2009; Ade and et al. 2008; Pryke and et al. 2009; Hinderks and et al. 2008; Brown and et al. 2009). Recently, Planck surveyor has been successfully launched, and is measuring CMB temperature and polarization anisotropy with very fine angular resolution. Using CMB data, we may test cosmological hypotheses and impose significant constraints on cosmological models (Dodelson 2003; Liddle and Lyth 2000; Mukhanov 2005). For the past years, WMAP data have gone through scrutiny, and various anomalies have been reported (Cruz et al. 2005, 2006, 2007, 2008; de Oliveira-Costa et al. 2004; Copi et al. 2004; Schwarz et al. 2004; Copi et al. 2006, 2007; Land and Magueijo 2005a, 2007; Rakić and Schwarz 2007; Park 2004; Chiang et al. 2003; Naselsky et al. 2004; Eriksen et al. 2004; Hansen et al. 2008; Hoftuft et al. 2009; Kim and Naselsky 2009). In direct relevance to this letter, Land and et al. have noted odd point-parity preference in WMAP data, but found its statistical significance was not high, given their estimator (Land and Magueijo 2005b). In this letter, we revisit the point-parity of the WMAP data with a slightly different estimator, and report the odd-parity preference of the WMAP power spectrum data at 99.6% level.

2. ANALYSIS OF THE WMAP DATA

For a whole-sky CMB analysis, temperature anisotropy $T(\theta, \phi)$ is conveniently decomposed in terms of spherical harmonics $Y_{lm}(\theta, \phi)$:

$$T(\hat{\mathbf{n}}) = \sum_{lm} a_{lm}\, Y_{lm}(\hat{\mathbf{n}}),$$

where a_{lm} is a decomposition coefficient, and $\hat{\mathbf{n}}$ is a sky direction. For a Gaussian seed fluctuation model, decomposition coefficients satisfy the following statistical properties:

$$\langle a_{lm} \rangle = 0$$
$$\langle a^*_{lm} a_{l'm'} \rangle = C_l\, \delta_{ll'} \delta_{mm'},$$

where $\langle \ldots \rangle$ denotes the average over the ensemble of universes. Given a standard cosmological model, we expect

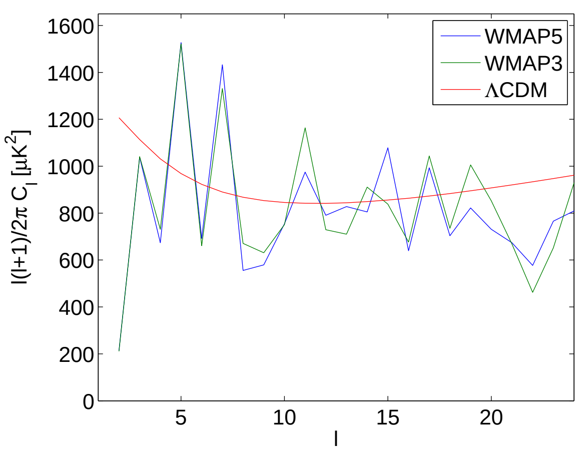

Figure 1. CMB power spectrum: ΛCDM model (red), WMAP 5 year data (blue), WMAP 3 year data (green)

Sach-Wolf plateau for CMB power spectrum on low multipoles (Dodelson 2003):

$$l(l+1)C_l \sim \text{const.} \qquad (1)$$

In Fig. 1, we show the WMAP 5 year, 3 year data and the theoretical power spectrum of the WMAP concordance model (Hinshaw and et al. 2007; Nolta and et al. 2008; Komatsu and et al. 2009). In comparison with WMAP 3 year data, WMAP 5 year data is expected to have more accurate calibration and less foreground contamination (Hinshaw and et al. 2009; Nolta and et al. 2008; Hill and et al. 2009).

Spherical harmonics behave under parity inversion as follows (Arfken and Weber 2000): $Y_{lm}(\hat{\mathbf{n}}) = (-1)^l\, Y_{lm}(-\hat{\mathbf{n}})$. Therefore, power asymmetry between

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even and odd multipoles may be thought as power asymmetry between even and odd parity map, because a map consisting of even(odd) multipoles possesses even(odd) parity. Hereafter, we will denote it as 'parity asymmetry'. In Fig. 2, we show $(-1)^l l(l+1)/2\pi\,(C_l^{\rm WMAP} - C_l^{\Lambda\rm CDM})$ at low multipoles. As shown in Fig. 2, most of them posses negative values, which indicates there exist power deficit (excess) in comparison to the ΛCDM model at most of even (odd) multipoles. In the case of WMAP5 data, there is only 3 points of positive values among 18 data points. A order-of-magnitude estimation shows that such events require the odd of $18!/(3!\,15!\,2^{18}) \approx 0.003$. However, power spectrum is estimated from cut-sky data to avoid diffuse Galactic foreground contamination. Therefore, statistical fluctuation in estimated C_l is correlated among multipoles. In order to investigate odd of the parity asymmetry rigorously, we have produced 10^4 simulated CMB maps (HEALPix Nside=8) of Gaussian ΛCDM model. We have degraded the WMAP processing mask (Nside=16) to Nside=8, and set pixels to zero, if any of their daughter pixels is zero. After applying the mask, we have estimated power spectrum from cut-sky maps by a pixel-based Maximum-Likelihood method. Instrument noise is neglected in simulation, since noise is subdominant on multipoles of interest (e.g. S/N ~ 100 for C_l at $l = 30$) (Nolta and et al. 2008). Bearing Eq. 1 in mind, we consider the following quantities:

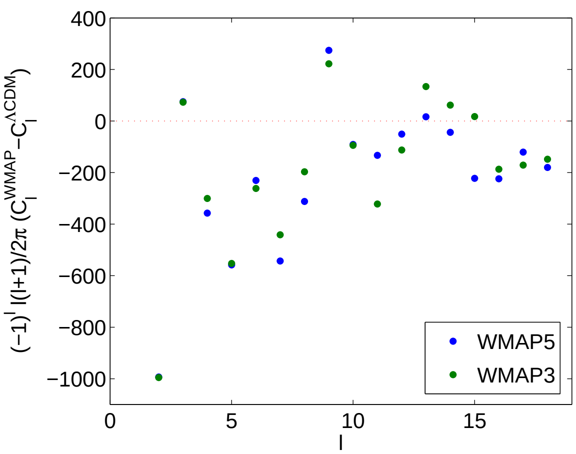

Figure 2. $(-1)^l\times$ difference between WMAP power spectrum data and ΛCDM model

$$P^+ = \sum (l + 1 - 2\left\lfloor\frac{l+1}{2}\right\rfloor)\, l(l+1)/2\pi\, C_l \qquad (2)$$

$$P^- = \sum (l - 2\left\lfloor\frac{l}{2}\right\rfloor)\, l(l+1)/2\pi\, C_l \qquad (3)$$

where $\lfloor\cdots\rfloor$ denotes the greatest integer smaller than or equal to the argument. Using the WMAP power spectrum data and simulations respectively, we have computed the ratio P^+/P^- for various multipole ranges $2 \le l \le l_{\rm max}$, where $l_{\rm max}$ is between 3 and 23. By comparing P^+/P^- of the WMAP data with simulation, we have estimated p-value, where p-value denotes fractions of simulations as low as P^+/P^- of the WMAP data. In Fig. 3, we show p-value of WMAP5 and WMAP3 respectively for various $l_{\rm max}$. Fig. 3 shows lowest p-value for $l_{\rm max} = 18$, where p-values are 0.004 and 0.0099 for WMAP5 and WMAP3 respectively. In other words, there exists anomalous odd-parity preference at multipoles ($2 \le l \le 18$). As shown in Fig. 3, WMAP5 possesses more anomalous odd-parity preference than WMAP3, while WMAP5 data have more accurate calibration and less foreground contamination (Hinshaw and et al. 2009; Hill and et al. 2009; Nolta and et al. 2008). Therefore, we find it unlikely that calibration or foregrounds are the source of the anomaly. It should be also noted that the anomaly is associated with the WMAP power spectrum data, in which most efforts have been exerted to minimize systematics.

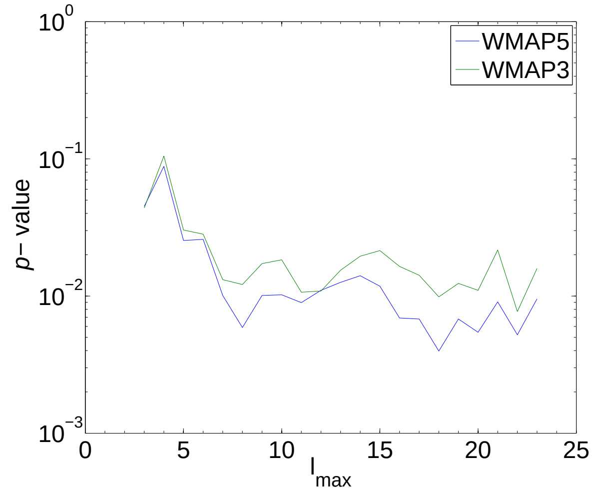

Figure 3. Probability of getting P^+/P^- as low as WMAP data for multipole range $2 \le l \le l_{\rm max}$.

It has been known that CMB quadrupole power of WMAP data is unusually low, compared with the theoretical value (de Oliveira-Costa et al. 2004). Therefore, one may attribute the anomalous parity asymmetry of the WMAP data to low quadrupole power. As shown in Fig. 3, the parity asymmetry persists over extended range of multipoles, and the parity asymmetry on multipoles ($2 \le l \le 18$) is most anomalous. Therefore, we may not simply attribute the parity asymmetry to low quadrupole power. For multipole range ($2 \le l \le 18$), we find $P^+/P^- \approx 1.1$ is most likely, while P^+/P^- of WMAP5 and WMAP3 are 0.69 and 0.734 respectively. In Fig. 4, we show P^+/P^- values of WMAP data and cumulative distribution of P^+/P^- for 10^4 simulated maps.

We have also estimated p-value, using whole-sky simulation (i.e. no mask), and obtained 0.0024. The difference from the cut-sky result is attributed to the increased statistical fluctuation in cut-sky C_l estimation. By using whole-sky simulations, we have also investigated p-value for $l_{\rm max} \gg 23$, but have not found the statistical significance as high as $l_{\rm max} = 18$.

3. DISCUSSION

In the previous study (Land and Magueijo 2005b), the parity asymmetry under point reflection as well as mirror reflection was noted, but point-parity was not given enough attention, since they found the statistical significance was not high. Investigating the WMAP power

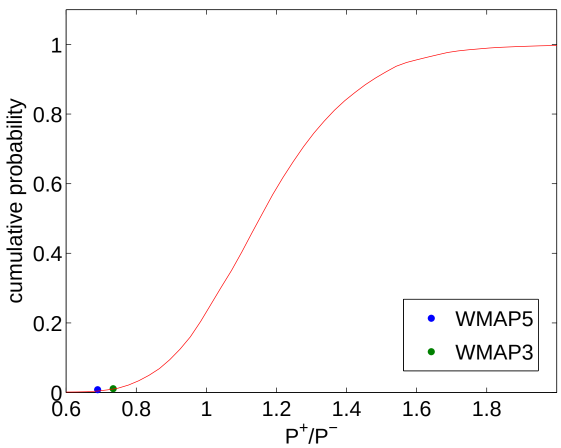

Figure 4. Parity asymmetry at multipoles ($2 \leq l \leq 18$): cumulative distribution of P^+/P^- for 10^4 simulated maps (red), P^+/P^- of WMAP5 (blue) and WMAP3 (green)

spectrum with a slightly different estimator, we found the odd-parity preference of the WMAP data ($2 \leq l \leq 18$) at 99.6% level (mask) and at 99.76% level (no mask). Higher parity asymmetry in WMAP5 data indicates that WMAP systematics is unlikely to be the source for the parity asymmetry. However, we do not completely rule out non-cosmological origins, and defer a rigorous investigation on cosmological or non-cosmological origin to a separate publication.

One may attribute low P^+/P^- of the WMAP data simply to low quadrupole power. However, as shown in Fig. 3, the anomalous parity asymmetry (i.e. low p-value) persists over extended range of multipoles. Therefore, we find it rather likely that low quadrupole power is part of this parity asymmetry anomaly. It was also shown that hemispherical power asymmetry is much more anomalous at multipoles ($2 \leq l \leq 19$) than multipoles ($20 \leq l \leq 40$) (Eriksen et al. 2004). Given all these circumstantial evidences, we find it likely that there exists an underlying common origin for the anomalies (e.g. hemispherical power asymmetry, low quadrupole power and parity asymmetry), whether it may be cosmological or WMAP systematics.

We are grateful to an anonymous referee for helpful comments, which leads to improvements of this letter. We are grateful to Changbom Park, Gary Hinshaw and Glenn Starkman for useful discussion. We acknowledge the use of the Legacy Archive for Microwave Background Data Analysis (LAMBDA). Our data analysis made the use of HEALPix (Gorski et al. 1999, 2005). This work is supported in part by Danmarks Grundforskningsfond, which allowed the establishment of the Danish Discovery Center. This work is supported by FNU grant 272-06-0417, 272-07-0528 and 21-04-0355. This work is supported in part by Danmarks Grundforskningsfond, which allowed the establishment of the Danish Discovery Center.

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